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Geographic Distribution of *Synanthedon sequoiae* and Host Plant Susceptibility on Monterey Pine in Adventive and Native Stands in California (Lepidoptera: Sesiidae)

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Abstract.—A systematic survey of larval *Synanthedon sequoiae* in adventive and native California stands of Monterey pine, *Pinus radiata,* indicated that the insect is mostly restricted to urban northern California. High densities of *S. sequoiae* were found north of San Francisco to Ft. Bragg in mostly inland valleys; around the southern portion of the San Francisco Bay; and around Monterey Bay. *Pinus radiata, P. patula* and *P. thunbergiana* were preferred hosts in urban areas; whereas *P. canariensis, P. halepensis* and *P. pinea* appeared largely resistant. *Synanthedon sequoiae* was significantly more abundant on host trees that had been pruned. The current practice of planting fast-growing pines, especially Monterey pine, in urban landscapes makes it likely that *S. sequoiae* will spread more widely through the state, eventually establishing in the Central Valley and in southern coastal cities. An isolated infestation in southern California and another in the Sierra-Nevada foothills support this possibility.

The sequoia pitch moth, *Synanthedon sequoiae* (Hy. Edwards),[1] occurs throughout western North America (Essig, 1926; Keen, 1952; Ohmart, 1981). Larvae feed and develop locally on phloem, cambium and, to a limited extent, on xylem tissues in branches and trunks of numerous native and exotic pine species (Weidman and Robbins, 1947) and on Douglas fir, *Pseudotsuga menziesii* (Mirb.) (Furniss and Carolin, 1977). Their feeding results in a colorful, red-brown mass of pitch and frass that protrudes noticeably from the wood substrate. Occasionally, this localized feeding causes weakened branches, but rarely branch dieback. Two reports (Brunner, 1914; Powers and Sundahl, 1973) suggest that under certain conditions *S. sequoiae* may become a forest pest. However, greatest concern for the insect stems from the unsightliness of pitch masses on ornamental trees (Payne, 1973; Ohmart, 1981; Koehler et al., 1983).

Although some general biological and behavioral information has been generated on *S. sequoiae,* much remains to be learned about its habits. Interest in the insect increases yearly due to a general awareness of its potential as a pest in ornamental landscapes. Information gaps include the lack of data on its current distribution in specific geographic areas, especially where pines are being used extensively in landscape plantings. Further, although *S. sequoiae* is known to use numerous pine species as hosts (Weidman and Robbins, 1947), preferred and non-preferred (resistant) species have yet to be appropriately designated. Finally,

[1] Formerly in the genus *Vespamima.*

several factors that render a host attractive have been suggested (see above references), but more work is needed on this aspect. In particular, previous host damage appears to be the most important factor predisposing a tree to infestation (Weidman and Robbins, 1947; Powers and Sundahl, 1973; Koehler et al., 1983).

In this paper we report results of a survey that systematically examined the distribution of *S. sequoiae* on Monterey pine in adventive (mostly urban) and native stands in California. Tabulated infestation sites on surveyed trees (esp. pruned versus unpruned) provided new insights on the attraction of *S. sequoiae* to its host trees. Finally, an assessment of preferred ornamental pine species in urban areas and an evaluation of potential for spread to new areas are offered.

Methods and Materials

Monterey pine was used in 1981 as the primary host for surveying *S. sequoiae* infestations in numerous adventive and in three native endemic stands. Suitability as an index host derives from its known wide-spread distribution in California and general attractiveness to the insect (Engelhardt, 1946; Payne, 1974; Koehler et al., 1983). Five different geographic zones were recognized and used in the survey (Fig. 1). The first of these was the north coastal zone. The second was the San Francisco Bay Area, which included the northern, southern and eastern sections of the Bay Area. The third zone was the central coastal region that extended from just south of San Jose along the coast to just beyond Santa Barbara in southern California. The fourth was the Central Valley, which extended from Redding to Bakersfield. Finally, the south coastal zone included the greater southern California coastal region. Specific adventive sites within each zone were preselected on a map at intervals of approximately 30 km. Native sites, all of which were in the central coastal zone, were selected in different representative sublocations that were easily accessible (steep hillside forests were avoided).

Forty Monterey pines were selected for survey in adventive and native sites in zones I–III from northern California (Fig. 1). In some Central Valley and southern coastal sites (zones IV and V) it was not always possible to locate 40 planted Monterey pines. Where this was a problem, other pine species known to host *S. sequoiae* were surveyed to supplement the available Monterey pines, the combination of which amounted to 40 sampled trees.

In adventive stands (usually urban plantings in cities), about half the trees were unpruned and half were pruned. Pruning ranged from one or two branches sawed close to the trunk to a complete pruning of all branches up to three meters on the trunk. Adventive stands consisted of variously aged hedgerow and specimen trees in industrial and recreational parks, around schools, or in wind breaks along coastal roads. Estimated tree age ranged from 6–30 years; however, surveyed trees at a given adventive location were usually of one age class. On rare occasions, two or three smaller groups of trees (each variously aged) had to be sampled within a few hundred meters to achieve a sample size of 40.

In each of the three native Monterey pine stands on mainland California (Ano Nuevo, Monterey and Cambria) three subsites were selected for survey (Fig. 1). Forty unpruned trees of mixed ages were chosen at each of these nine subsites. Natural branch pruning, which was common on older trees in native stands, was not considered equivalent to artificial pruning in urban areas.

Trees in both types of stands were individually inspected on trunks, branches

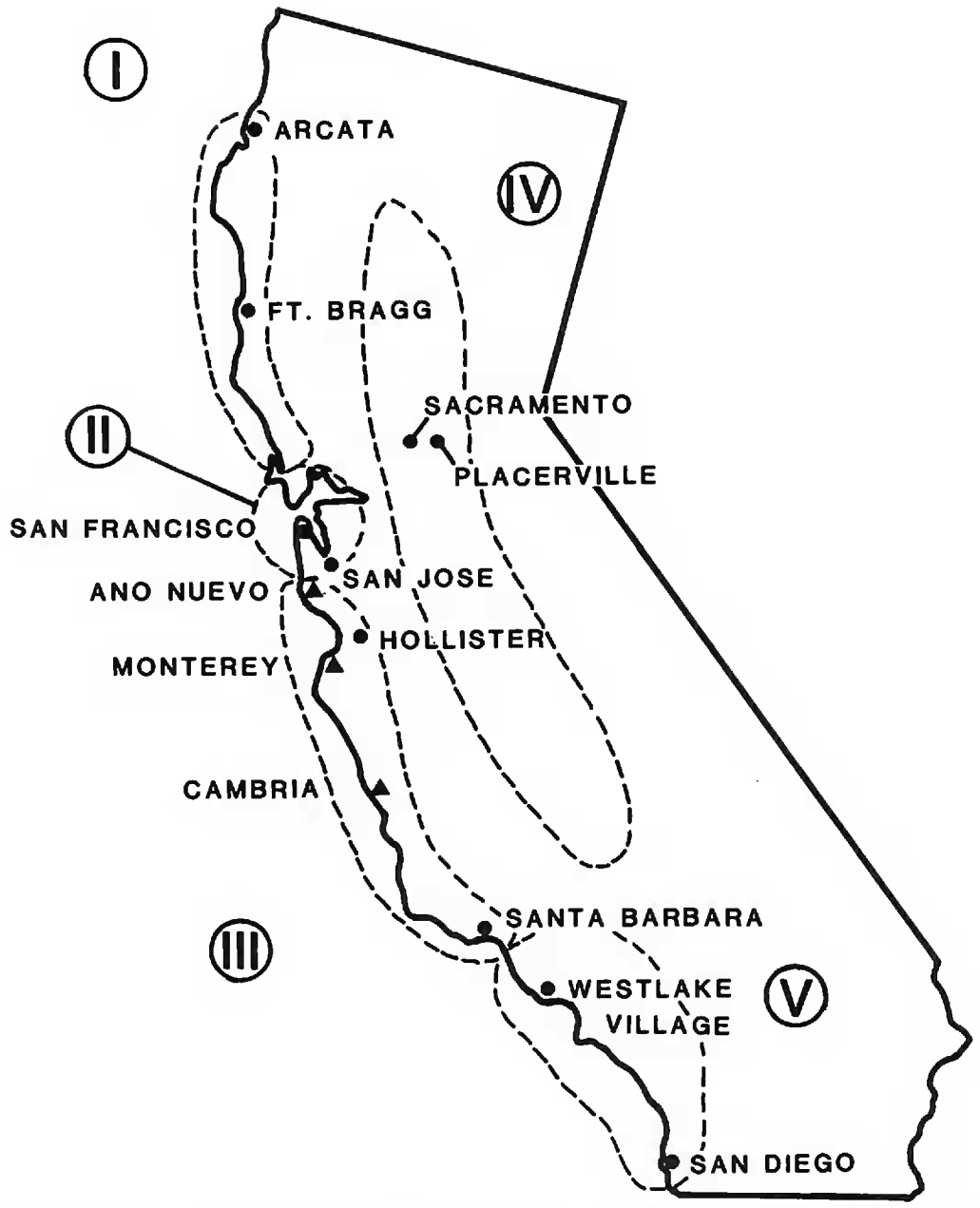

Figure 1. Geographic zones surveyed for *S. sequoiae* pitch masses. Zone I: north coastal; zone II: San Francisco Bay Area; zone III: central coastal; zone IV: Central Valley; zone V: south coastal. ▲—endemic stands of Monterey pine; ●—cities having general geographic significance or unique *S. sequoiae* infestations.

and nodal/internodal areas, as well as the unions where pine cones attached to branches. To assist in this process binoculars were used for many of the taller trees. On rare occasions where infestations were suspected high in the crown, trees were climbed to make a closer inspection. Very large, old trees, although rarely encountered, were bypassed because of the difficulty of assessing infestations at the highest crown levels.

Three distinct infestation types, new, old and reinfestations, on trunks and branches were recognized. New infestations were reddish-brown in color, had a glistening, pitchy appearance and protruded noticeably from the wood substrate. Old infestations were grey in color, hardened, protruding or flat and were often large and cracked in appearance. They remain recognizable on trees for several years. Finally, reinfestations were characterized by new flows of red-brown resin and frass that exuded from the margins and/or center of old pitch masses.

An arbitrary system of infestation categories was established to generally assess low, moderate and high levels of pitch masses (all types) in the surveyed stands. A low level had 1–40 infestations; 41–80 constituted the moderate level; and a high level consisted of more than 80 infestations.

Collection records of *S. sequoiae* were examined and compiled from the following California collections and museums: State Department of Food and Agriculture, Sacramento; California Academy of Sciences, San Francisco; Natural History Museum of Los Angeles County, Los Angeles; University of California, Riverside.

Results

California Survey Results

New, old and reinfestations of *S. sequoiae* were noted and compiled for each of 97 adventive sites and 9 native subsites in the California survey. Sampling revealed that the insect was established in the north coastal region of California which includes geographic zones I–III (Fig. 1, Tables 1 and 2). The survey did not detect *S. sequoiae* in the Central Valley or the south coastal region (zones IV and V in Fig. 1 and additional distribution information below). Overall, much higher levels of *S. sequoiae* were recorded on trees in adventive as compared to native stands (Tables 1 and 2).

Using the arbitrary system of infestation categories, each site was placed into a low, moderate or high infestation level. All sites were then grouped to determine where the insect was least and most abundant in the state. Most sampled areas had no infestations or low levels, including 8 of 9 natural areas (Tables 1 and 2). Only the adventive stands at Willits and Fremont I and the Monterey B natural site were found to contain moderate levels. Twelve sites, all adventive, had high levels and these were distributed primarily in three regions: two in the north coast (Ukiah and Napa), seven around the south end of San Francisco Bay, and three in the north section of the central coastal zone. Sites at Mountain View, Sunnyvale, San Jose I and II and Carmel had exceptionally high infestation levels with total infestations exceeding 300 per site (Table 1). Although high densities were recorded from these three regions, a few of the included stands in each region had relatively few or no pitch masses (e.g., Cloversdale, Healdsberg and Rohnert Pk. in zone I; San Carlos and Menlo Pk. in zone II; Davenport and Salinas in zone III; see Table 1).

The percentage of trees infested was almost always greater in pruned versus unpruned adventive stands (Table 1). San Jose II was an obvious exception to this generality. It was common for some trees at a site to be highly infested while other surrounding or nearby trees had only a few pitch masses. This uneven distribution is reflected in part by high variances of the means reported in Table 1. There was no obvious reason for differences in the uneven distribution of pitch masses on comparable nearby trees. Other workers (cf. Powers and Sundahl, 1973) have also observed clear differences in infestation levels among trees in affected stands.

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[1] New, old and reinfestations.

[2] Pruned and unpruned *P. radiata, halepensis* and *thunbergiana,* and to a limited extent *canariensis, muricata* and *sabiniana.*

[3] Pruned and unpruned *P. halepensis* only.

[4] Pruned and unpruned *P. halepensis, thunbergiana,* and to a lesser extent *canariensis.*

Table 1. Numbers of infestations,[1] percent trees infested and mean numbers (±SD) of *Synanthedon* on unpruned and pruned trees in adventive sites in five geographic zones (see Fig. 1). Unless otherwise indicated, surveyed trees were Monterey pine.

Location	Nos. infestations		% trees infest.		$\bar{x}$ nos. infest. per infest. tree	
	Unpruned	Pruned	Unpruned	Pruned	Unpruned	Pruned
I. North Coastal						
Willits	0	46	0%	21%	0	11.5 ± 14.7
Ukiah	4	85	14	63	1.3 ± 0.6	7.1 ± 6.0
Healdsburg	0	2	0	8	0	1.0 ± 0
Rohnert Pk.	3	0	21	0	1.0 ± 0	0
Napa	9	212	33	64	1.5 ± 0.6	15.1 ± 22.0
Albion, Arcata, Cloverdale, Eureka, Ft. Bragg, Jenner, and Pt. Arena: none with infestations.						
II. San Francisco Bay Area						
Novato	0	3	16	0	1.0 ± 0	0
San Rafael	2	0	5	0	2.0 ± 0	0
Mill Valley	0	5	0	15	0	1.7 ± 0.6
San Bruno	0	35	0	47	0	3.9 ± 3.1
Burlingame	0	245	0	53	0	11.3 ± 21.7
Menlo Pk.	16	17	31	17	4.0 ± 4.8	3.4 ± 3.4
Mt. View	70	240	21	90	17.3 ± 17.6	12.6 ± 16.1
Sunnyvale	14	336	45	95	1.6 ± 0.9	17.7 ± 16.2
Santa Clara	29	60	30	70	4.8 ± 3.4	4.3 ± 1.9
San Jose I	100	314	80	95	6.3 ± 3.8	17.3 ± 16.9
San Jose II	429	168	95	80	22.6 ± 11.5	10.5 ± 11.5
Livermore	73	216	54	89	10.4 ± 9.5	9.0 ± 8.4
Fremont I	0	41	0	41	0	2.7 ± 2.1
Fremont II	0	4	0	20	0	1.0 ± 0
Hayward	0	2	0	10	0	1.0 ± 0
Castro Valley	0	1	0	5	0	1.0 ± 0
Oakland	1	0	5	0	1.0 ± 0	0
Piedmont	0	1	0	5	0	1.0 ± 0
Albany	0	9	0	8	0	3.0 ± 2.6
Vallejo II	0	4	0	5	0	4.0 ± 0
Alamo, Berkeley, Concord, Crockett, Daly City, El Cerrito, El Sobrante, Richmond, San Carlos, San Francisco, San Gregorio, San Leandro, Sausalito, Stinson Beach, Union City and Vallejo I: none with infestations.						
III. Central Coastal						
Davenport	0	1	0	20	0	1.0 ± 0
Santa Cruz	27	157	50	69	3.9 ± 6.7	8.7 ± 11.1
Watsonville	24	100	38	75	2.7 ± 1.4	8.3 ± 8.9
Salinas	0	23	0	14	0	7.7 ± 7.6
Carmel	28	459	38	96	4.7 ± 5.2	20.9 ± 17.9
Atascadero, Gaviota, Lompoc, Los Padres, Lucia, Morro Bay, Pismo Beach, San Miguel and Santa Maria: none with infestations.						
IV. Central Valley						
Bakersfield,[2] Chico, Davis, Delano,[2] Fairfield,[2] Madera,[2] Merced,[2] Modesto, Orland,[3] Oroville, Red Bluff, Redding, Sacramento,[2] Selma,[2] Stockton, Tracy,[2] Tulare,[2] Turlock,[2] Yuba City/Marysville: none with infestations.						
V. South Coastal						
Beverly Hills,[2] Buena Park,[2] Chula Vista, Compton,[2] Laguna Hills,[2] Long Beach,[2] National City,[2] North Hollywood,[2] Oceanside, Pasadena,[2] Pomona,[2] San Clemente,[2] San Diego,[4] Simi Valley, Ventura[2] and Woodland Hills[2]: none with infestations.						

Table 2. Numbers of infestations,[1] percent trees infested and mean numbers (±SD) of *Synanthedon* infestations on 40 Monterey pines at each native subsite.

Location	Nos. infestations	% trees infest.	$\bar{x}$ no. infest. per infest. tree
Ano Nuevo[2]			
Site C	4	5	2.0 ± 1.4
Monterey			
Site A	17	25	1.7 ± 0.9
Site B	64	48	3.4 ± 2.4
Site C	9	15	1.5 ± 0.8
Cambria			
Site A	29	25	2.9 ± 1.8
Site B	11	1	2.8 ± 1.0
Site C	17	23	1.9 ± 1.5

[1] New, old and reinfestations.
[2] No. infestations at subsites A and B.

The type of infestation (i.e., new, old or reinfestation) was tabulated for each site to assess the relative infestation age of a particular stand. In the following account, only those sites having greater than 20 infestations were examined (Tables 1 and 2). In virtually all adventive and native stands there were considerably more old or new infestations than reinfestations. Further, most sites (71%) had more old as compared to new infestations; the opposite relationship was noted at Santa Clara, Santa Jose I, Livermore, Santa Cruz, Watsonville and Salinas. In these cases, it appeared that the trees supported incipient or growing populations of *S. sequoiae.*

Examination of tabulated data provided information on preferred infestation sites on individual trees (Tables 3 and 4). Comparing overall infestations on trunks and branches of adventive trees, approximately twice as many were found on the trunks (Table 3). Pruned sites on both trunks and branches had about three times as many infestations as did the respective unpruned sites, and the differences in both cases were significant (t-test, $P = 0.005$). On the lower halves of trees about four times as many infestations were recorded as compared to the upper halves (each half included trunks and branches) (Table 3). Further, pruned areas had significantly more infestations than unpruned areas, regardless of tree half. The same general infestation patterns were also observed on native trees where substantially more infestations were recorded on trunks versus branches and on lower versus upper halves of trees (Table 4).

Pitch masses were found on adventive or native trees at the following specific locations: nodes (bases of branches), internodes, injured or pruned areas, previous infestations, and pine cone attachment points on branches. To gain insight on which locations were preferred, new infestations only were tabulated from all survey trees (Table 5). In the case of unpruned trees, nodes and internodes were the preferred sites. To a slightly lesser extent, previous infestations were also preferred. New pitch masses were relatively uncommon on injured sites and pine cone bases in this group of trees. In the case of pruned trees, nodes and internodes had considerably more pitch masses than the other sites, including those injured or pruned. Previous infestations and pine cone bases were the least preferred in this group.

Table 3. Total numbers of infestations[1] on trunks versus branches and on lower versus upper halves of unpruned and pruned Monterey pines in adventive stands.

Location	Total nos. of infestations per zone			
	Trunk		Branches	
	Unpruned	Pruned	Unpruned	Pruned
N. Coastal	12	254	4	91
S.F. Bay Area	491	1078	243	616
Central Coastal	53	448	21	292
Totals:	556	1780	268	999
$P = 0.005$	$t = 5.19$		$t = 4.17$	
	Lower half		Upper half	
N. Coastal	13	279	3	65
S.F. Bay Area	647	1352	87	342
Central Coastal	59	548	15	190
Totals:	719	2179	105	597
$P = 0.005$	$t = 4.45$		$t = 5.1$	

[1] New, old and reinfestations.

In 1943 and 1944, Weidman and Robbins (1947) recorded the distribution and numbers of *S. sequoiae* pitch masses on 3690 pine trees at the Eddy Arboretum in Placerville, California (Fig. 1). They found evidence of the insect on 33 pine species and four hybrids. Based on total numbers of pitch masses per 100 trees, they constructed a list of the most frequently infested pine species. According to their tabulation, Monterey pine was one of the least infested pines. However, it seems that variously-treated trees at the arboretum may have influenced this tabulation. For example, some pine species were pruned; others were not. A few pine species were extensively drilled by sapsucking woodpeckers; others were scarcely affected or lacked drillings entirely. Further, infestations were often localized within the arboretum. Thus, the Weidman and Robbins (1947) listing serves best as guide only for those species that are likely to host *S. sequoiae.* To develop a more accurate scale of relative suitability or susceptibility by host pine species would involve a considerable testing effort, exposing reared adult moths to trees standardized for such characteristics as age, size and pruning activity.

Although this type of testing was beyond the scope of the current investigation, a group of similarly-treated ornamental pines was surveyed in the city of San Jose to develop information on the question of relative host susceptibility. San Jose

Table 4. Total numbers of infestations[1] on trunks versus branches and on lower versus upper halves of Monterey pines in native stands.

Location	Total nos. of infestations per site			
	Trunk	Branches	Lower ½	Upper ½
Ano Nuevo	4	0	4	0
Monterey	65	25	65	25
Cambria	54	3	45	12
Totals:	123	28	114	37

[1] New, old and reinfestations.

Table 5. Total numbers of new infestations only on five specific sites on adventive and native Monterey pines.

Infestation site	Nos. of new infestations	
	Unpruned	Pruned
Nodal (intact)	198	274
Internodal (intact)	157	299
Injury and/or pruning	19	121
Previous years' infest.	141	55
Pine cone base	8	43

was chosen since the insect was found to be very active there (Table 1). Representatives of five common pine species were selected throughout the city (Table 6). They ranged in age from 10–25 years, and each tree had some evidence of past flush pruning on the trunk. Comparing the San Jose results with those of Weidman and Robbins (1947), there was agreement in relative susceptibility for three species, *P. canariensis, P. pinea* and *P. thunbergiana.* However, for three species (*radiata, patula* and *halepensis*) there were considerable differences in survey results. With regard to *P. halepensis,* our supplemental observations in other California cities (unpub.) indicated that this species is only an occasional host, especially if unpruned (see also results of Westlake Village survey below).

Additional sites throughout California were examined, and these locations provide supplemental information on the current geographic distribution of and relative susceptibility of host pine species to *S. sequoiae.*

Ft. Bragg.—Surveyed Monterey pine in this city showed no evidence of *S. sequoiae* (Table 1), which is consistent with its general distribution in this geographic zone (Fig. 1). However, a later examination of another group of Monterey pines in Ft. Bragg revealed that the insect occurred there in low numbers. Rather than resurvey the second group, two other common pines, *P. muricata* and *P. contorta* were examined for the insect. Twenty pruned and 20 unpruned ornamental trees, mostly 5–20 years old, of each species showed the insect in low densities in *P. muricata* (total of 39 masses) and in high densities in *P. contorta* (total 126 masses). These results indicated that *S. sequoiae* can effectively use other pine species as hosts, even in the presence of Monterey pine. It is noteworthy that both pines occur natively in and around Ft. Bragg, and thus the infestation was considered long-standing in the area.

Hollister.—At a nursery just north of the city, about 60,000 Monterey pines are grown in pots for use as Christmas trees (Fig. 1). Trees were first planted at this site in 1980, and *S. sequoiae* first appeared on a few trees in late 1983. A survey in early 1985 of several hundred trees in three age classes revealed the following distribution. One year old trees were almost entirely free of the insect; two year olds had a frequency of about 1%; three year olds had a 10% infestation rate. Most infested trees had a single pitch mass.

Although *S. sequoiae* is considered new to this locality, its potential as a major pest in such a pine plantation is recognized on the basis of several factors. It does not usually infest such small sized trees; larger diameter wood is generally required to support developing larvae. Further, the vigorous handling trees receive during repotting and shearing, and the rapid growth they experience through generous applications of drip-irrigated water and fertilizer may be predisposing them to

Table 6. Numbers of infestations and percent trees infested with *Synanthedon* on pruned *Pinus* species in San Jose.

Pinus species	*n*	Nos. infestations	% trees infested	Est. relative attract.	Relat. attract. cf. Weidman & Robbins ('47)
P. radiata I[1]	20	314	80	hi	low
P. radiata II[2]	20	168	95	hi	low
P. patula	16	117	69	hi	low
P. thunbergiana	20	37	55	mod	mod
P. halepensis	20	23	40	low?	mod–hi
P. canariensis	20	0	0	NR[3]	none
P. pinea	20	0	0	NR[3]	low

[1] San Jose I from Table 1.
[2] San Jose II from Table 1.
[3] NR—none recorded. Occasionally, pruned or injured trees have been observed with a few pitch masses, however.

the insect. Finally, the nursery is in close proximity to Monterey Bay (zone III–Fig. 1), one of the regions where *S. sequoiae* was found in high densities (Table 1).

Westlake Village.—The Westlake Village Golf Course, located in the south coastal zone (Fig. 1), was the only site in southern California where *S. sequoiae* was found. The golf course was not part of the systematic survey, but rather it resulted from an information inquiry about the moth during the time of the statewide survey in 1981. The site contained more than 300 Monterey pine, with some *P. halepensis* and *P. pinea*; the majority of these trees were planted in 1967. Most Monterey pines were infested with the insect, and many were highly infested. Two trees were exemplary: one had 225–250 pitch masses; the second had 350–400 (new, old and reinfestations). Only a few infestations were found on some individuals of *P. halepensis,* and one infestation was located on *P. pinea.*

Infestations of *S. sequoiae* at Westlake differed from others in the state in two respects. First, the pitch masses were about twice as large as masses in any other location. The weight of some caused them to fall from trees and litter the edges of fairways. Secondly, masses were commonly found on the upper trunk region and associated branches. This unique distribution appeared to be related to bark lesions that commonly occurred in the upper crown. Lesions were small and irregularly shaped and may have resulted from localized feeding by squirrels or other rodents. Although none of these mammals were actually sighted at Westlake, in Pacific Grove (Central Coastal zone, Fig. 1) squirrels have been observed chewing lesions of this type in Monterey pine branches.

The first pitch masses at Westlake were noticed by grounds keepers in 1980. By 1981, the numbers of new masses far outnumbered old ones, indicating that the population was still developing. Despite the observed high densities in 1981, it appeared that the golf course infestation was highly localized since various ornamental pines examined in 1982 in a residential neighborhood around the golf course showed no evidence of the insect. Further, at a nearby golf course in Camarillo, 10-year-old Monterey pines (and *P. halepensis*) showed similar lesions on branches and trunks but no evidence of *S. sequoiae.*

Placerville.—Pines at the Eddy Arboretum in Placerville were examined in 1981 and 1982 for pitch masses of *S. sequoiae.* A few masses were found on some

representatives of several pine species; however, none of the affected species appeared to be as susceptible as reported by Weidman and Robbin (1947) in their 1943–1944 assessment of the *S. sequoiae* infestation. Because of these low densities it was impossible to sort out the most and least susceptible pine species. Overall, the infestation was assessed as persisting at low densities, which may be characteristic of older trees that have not been damaged for several years.

Collection records from major California collections and museums were of limited use in supplementing the state distribution pattern of *S. sequoiae.* Most collections were taken from Monterey pine in northern California, especially around the south end of the San Francisco Bay and from the Carmel/Monterey area. In southern California, only a very few collections were available, and these were from pines in natural forests at higher elevations (~1500 m). One of these was taken from *P. coulteri* at the Arrowhead area of the San Bernardino Mountains. Two collections each were from *P. coulteri* and *P. jeffreyi* at Idyllwild (vicinity of Mt. Baldy) in the San Jacinto Wilderness Area.

Discussion

Overall results of the systematic survey, supplemental observations in specific locations and museum records indicated that *S. sequoiae* is mostly a coastal to somewhat inland insect in urban northern California. More specifically, the moth is found in relatively high densities in three general areas. The first extends from Ft. Bragg to San Francisco, just east of the coastal mountains (Fig. 1 and Table 1). The second area occurs around south San Francisco Bay (mostly San Mateo and Santa Clara Counties). Payne (1974) also noted a high frequency of *S. sequoiae* in Santa Clara Co. The third area is located around Monterey Bay, immediately coastal and slightly inland, and includes the cities of Santa Cruz, Watsonville, Hollister and Carmel.

Additional collecting from native pines (*P. coulteri, P. jeffreyi, P. ponderosa* and *P. sabiniana*) in the inland mountains of northern and southern California would probably reveal a more widespread distribution of the insect in the state. The observations at Placerville and collections from the San Bernardino and San Jacinto mountains provide evidence for this possibility. The long-standing infestations of *S. sequoiae* in Placerville and the new infestations at Hollister and Westlake Village also suggest that the insect has the capacity to establish high populations in new areas. The popular trend of using fast-growing pines in many urban California landscapes, especially in southern California and in the cities of the Central Valley, may increase the chances of new localized infestations.

Based on our observations statewide and the observations of other workers (Brunner, 1914; Engelhardt, 1946; Weidman and Robbins, 1947; Powers and Sundahl, 1973; Payne, 1974), it was possible to sort the urban ornamental pines into two major groups; preferred and non-preferred species. In the preferred category were *P. radiata, P. patula, P. thunbergiana, P. muricata, P. contorta* and *P. ponderosa* (the latter three species are only occasionally used in urban California landscapes). Pines showing resistance to *S. sequoiae* were *P. canariensis, P. halepensis* and *P. pinea. Pinus halepensis* can best be described as generally resistant, but susceptible under some circumstances. *Pinus canariensis, P. pinea* and *P. halepensis* become slightly more susceptible as hosts only if they have experienced substantial pruning or other mechanical damage.

Because of its rapid growth and desirable form, it is likely that Monterey pine will continue to be widely planted in urban California, despite its susceptibility to the moth. However, in areas where *S. sequoiae* is common, *P. halepensis* may be substituted for *P. radiata* owing to its general resistance to the insect and similarity in size, form, texture and needle color with *P. radiata.* It is likely that this option will only be considered by land owners and managers when *S. sequoiae* or other insect pests such as bark beetles severely damage Monterey pine. This was the case at Westlake Village Golf Course where *S. sequoiae* and *Ips* bark beetles threatened to seriously damage about one-third of the standing trees.

It seems clear that certain human activities, especially pruning or similar mechanical injury, predispose host trees to *S. sequoiae.* This was experimentally demonstrated by Koehler et al. (1983) and by our comparative survey on unpruned and pruned trees in adventive and native stands of Monterey pine. Other factors that render host trees more susceptible include the activities of rodents, woodpeckers (Weidman and Robbins, 1947), increment borers (Powers and Sundahl, 1973), and damage by moving vehicles and support wires/metal stakes left in place too long (Payne, 1974). Powers and Sundahl (1973) also suggest that rapidly growing trees have a higher risk of infestation by *S. sequoiae.* Our experience with fast-growing Monterey pines in Hollister and elsewhere support their observation. Overall, the evidence indicates that tree stress leading to bark rupture or reduced outer bark thickness will encourage entry of the insect.

Several other studies have demonstrated the relationship between increased borer infestations and human-induced tree stress. Potter and Timmons (1981) showed that trunk wounding and exposure to sun were the most important factors predisposing flowering dogwoods in Kentucky to the dogwood borer, *Synanthedon scitula* (Harris). Frankie and Koehler (1971) and Frankie and Ehler (1978) described how larval infestations of the cypress bark moth, *Laspeyresia cupressana* (Kearf.), increased on Monterey cypress that had been stressed through rapid growth and mechanical bark ruptures in urban California environments. Byers et al. (1980) reported that the smaller European elm bark beetle, *Scolytus multistriatus* (Marsh.) was more attracted to pruned limbs of European and Siberian elms compared to healthy, non-pruned limbs in California. Landwehr et al. (1981) found that native elm bark beetles, *Hylurgopinus rufipes* (Eichhoff), were more attracted to pruned versus unpruned American elms in Minnesota. Their work also showed that treating pruned sites with wound dressing compound would reduce the number of incoming bark beetles. Finally, collection notes by Engelhardt (1946) on U.S. sesiids suggest that larvae of several species are commonly associated with fast growing trees, especially in urban or suburban settings. The implication is obvious; that trees in well cared for human environments are apparently more attractive than conspecific hosts in natural environments. Engelhardt mentions that one sesiid, *Vitacea scepsiformis* (Hy. Edwards), is exceptional in this regard; it thrives on host plants in cultivation and is very rare or absent in natural habitats.

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Literature Cited

Brunner, J. 1914. The sequoia pitch moth, a menace to pine in western Montana. U.S. Dept. Agr. Bull. No. 111.

Byers, J. A., P. Svihra, and C. S. Koehler. 1980. Attraction of elm bark beetles to cut limbs of elm. J. Arboriculture, 6:245–246.

Engelhardt, G. P. 1946. The North American clear-wing moths of the family Aegeriidae. Bull. U.S. Nat'l Mus., 190:1–222.

Essig, E. O. 1926. Insects of western North America. The MacMillan Co., New York.

Frankie, G. W., and L. E. Ehler. 1978. Ecology of insects in urban environments. Ann. Rev. Entomol., 23:367–387.

———, and C. S. Koehler. 1971. Studies on the biology and seasonal history of the cypress bark moth, *Laspeyresia cupressana,* Can. Entomol., 103:947–961.

Furniss, R. L., and V. M. Carolin. 1977. Western forest insects. U.S. Dept. Agr. Misc. Publ. 1339.

Hall, R. W., and L. E. Ehler. 1980. Population ecology of *Aphis nerii* on oleander. Env. Entomol., 9:338–344.

Keen, F. P. 1952. Insect enemies of western forests. U.S. Dept. Agr. Misc. Publ. 273.

Koehler, C. S., G. W. Frankie, W. S. Moore, and V. R. Landwehr. 1983. Relationship of infestation by the sequoia pitch moth (Lepidoptera: Sesiidae) to Monterey pine trunk injury. Environ. Entomol., 12:979–981.

Landwehr, V. R., W. J. Phillipson, M. E. Ascerno, and R. Hatch. 1981. Attraction of the native elm bark beetle to American elm after the pruning of branches. J. Econ. Entomol., 74:577–580.

Ohmart, C. P. 1981. An annotated list of insects associated with *Pinus radiata* D. Don in California. Forest Research CSIRO, Div. Rept. No. 8.

Payne, P. B. 1974. Sequoia pitch moth on Monterey pine. Coop Exten., Univ. of California, OSA-270.

Potter, D. A., and G. M. Timmons. 1981. Factors affecting predisposition of flowering dogwood trees to attack by the dogwood borer. HortScience, 16:677–679.

Powers, R. F., and W. E. Sundahl. 1973. Sequoia pitch moth: a new problem in fuel-break construction. J. Forestry, 71:338–339.

Weidman, R. H., and G. T. Robbins. 1947. Attacks of pitch moth and turpentine beetle on pines in the Eddy Arboretum. J. Forestry, 45:428–433.